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(54) Polyphase ring core transformer and electrical power converter arrangement

(57) An electrical power converter comprises a ferromagnetic ring core 1 and two primary windings. Each primary winding comprises two winding portions 2, 4 and 3, 5 which are positioned diametrically opposite on the ring core 1. The winding portions 2, 4 and 3, 5 are connected in series and wound such that they create opposing magnetic effects which cancel with each other. The winding portions 2, 4 of one primary winding are positioned on the core 1 at right angles relative to those 3, 5 of the other primary winding. At least one separate and isolated secondary winding 23 and / or 24 is positioned on the core to supply output terminals. A direct current supply 18 may be connected via switch means 8 - 15 and capacitors 6 and 7 to induce a resonant signal within the primary windings. The primary windings may be formed using bifilar conductors and the polyphase secondary windings may be arranged in a star or delta configuration. The above arrangement may provide multiple voltage outputs with various relative phases and amplitudes and may be used in the medical treatment of hyperthermia or diathermy.

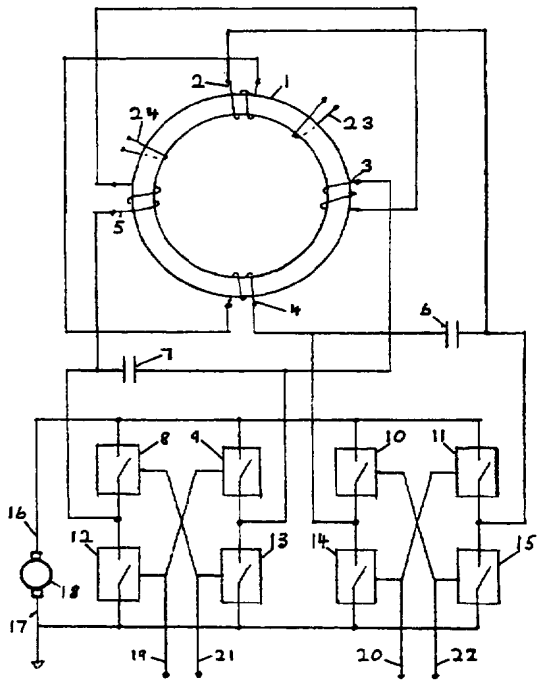

FIG. 1.

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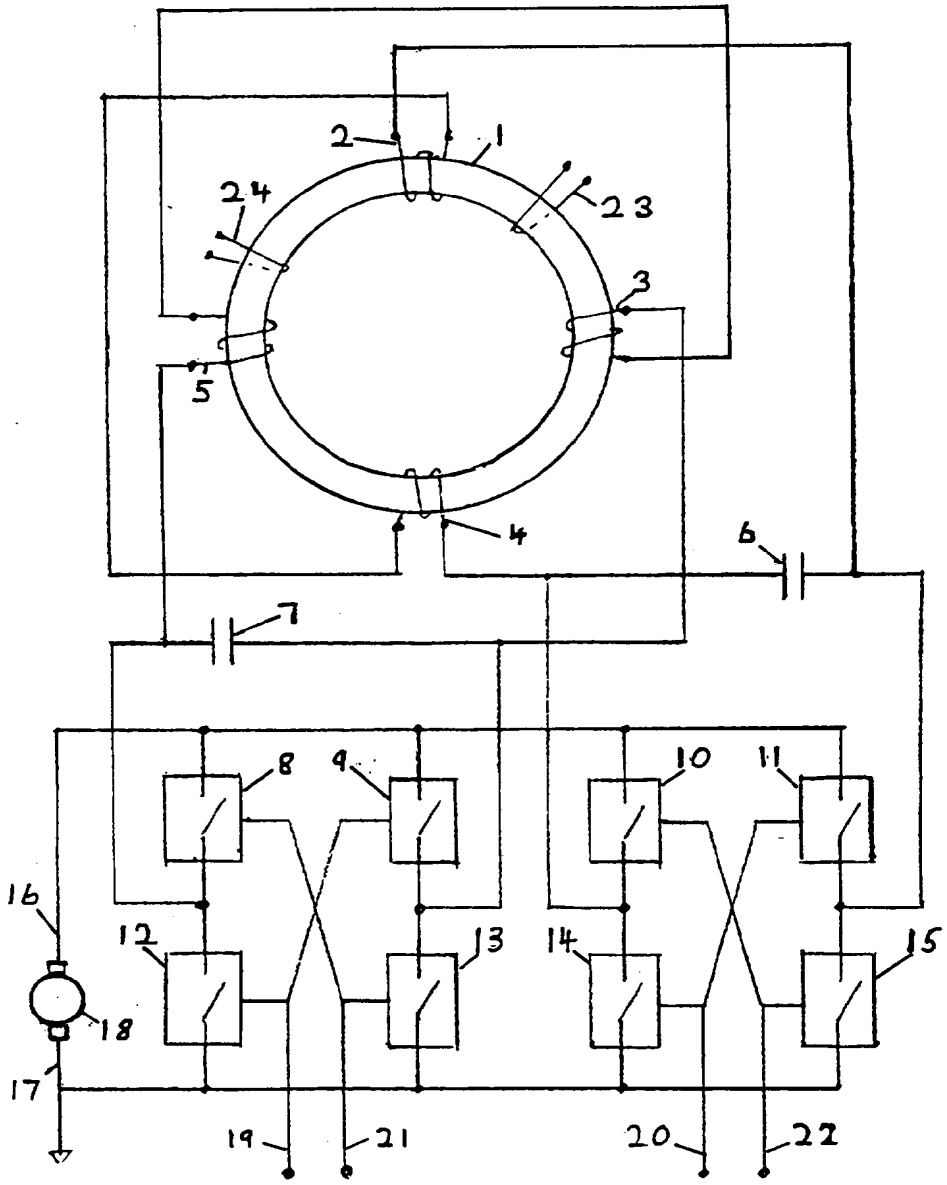

FIG. 1.

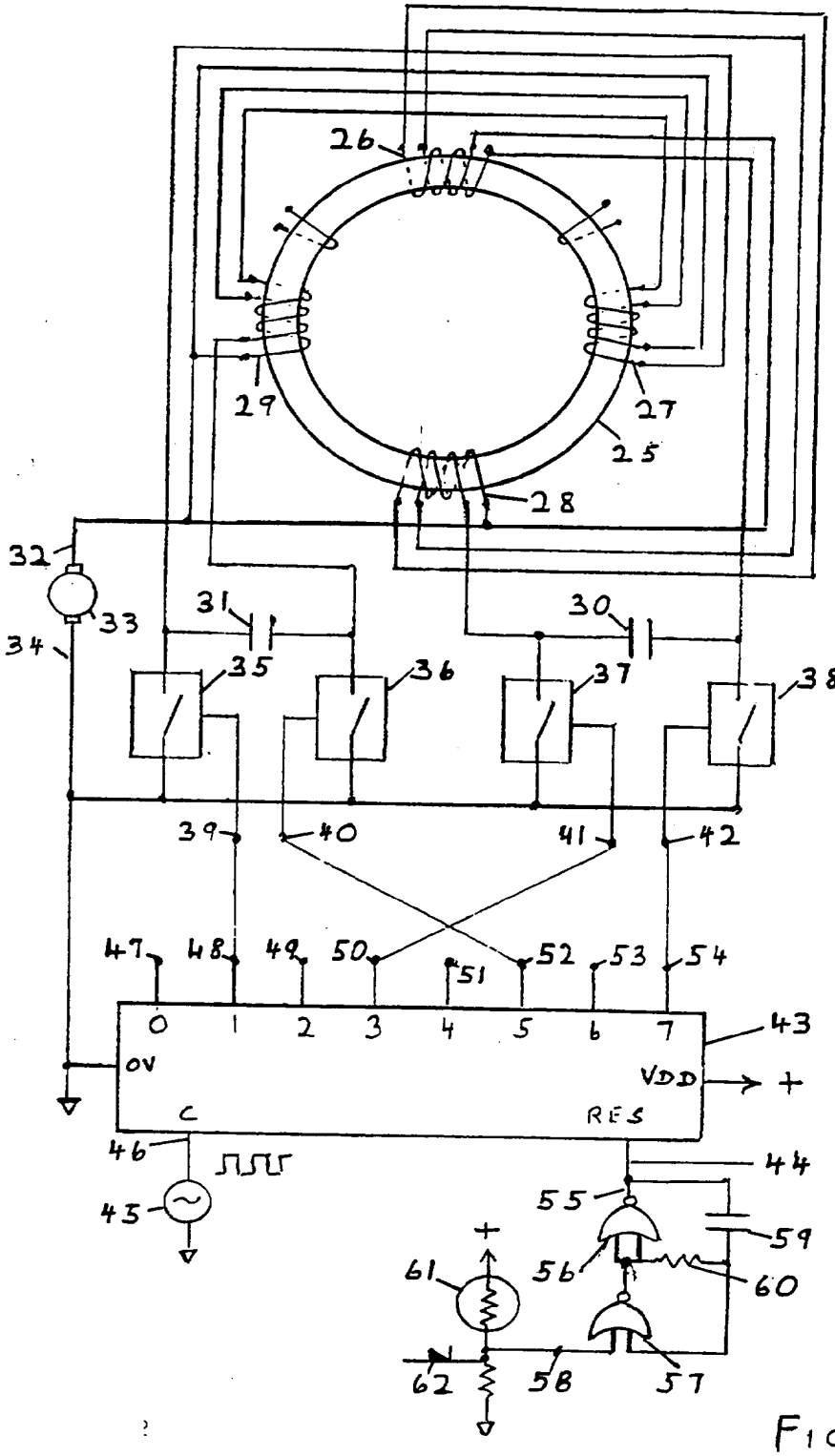
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FIG. 2.

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IMPROVEMENTS IN RELATION TO POLYPHASE ELECTRICAL GENERATORS APPLICABLE TO MEDICAL DIATHERMY

This invention relates to apparatus which generates power in the form of alternating electrical voltages between pairs of electrical output terminals, wherein each of said pairs of terminals may be isolated from others of said pairs, and wherein the magnitudes and relative phases of the currents flowing between said pairs of output terminals, when loads are applied, are predeterminable.

In the prior art, and in my British Patent Application no. 9403870.0, two or more transformers may be driven from a single alternating current power source, which may itself be of a polyphase type, or else from a single phase source through phase shifting components such as capacitors. In either event it is possible for each pair of said output terminals to be linked by a plurality of winding turns connected in series, said turns being wound in appropriate number upon each of said transformer cores so that each turn makes a voltage contribution from the particular transformer core upon which it is wound. Between each of said pairs of terminals there will then exist a resultant voltage, formed by the vector addition of voltages from the said individual turns.

By choosing for each pair of terminals appropriate numbers of turns, wound upon one or more of said transformer cores, a voltage of any desired magnitude and phase can be obtained. However without the mechanical complication of loose coupled turns, variation of phase is available only in coarse steps corresponding to one winding turn.

This type of generator may well be complex and bulky, containing many junctions between individual windings: these are undesirable where a high degree of electrical isolation is called for. A particular example is diathermy used in electro-surgery, where the patient must be well protected from currents flowing to earth and also from any currents derived from low frequency power supplies.

The object of this invention is to provide a single ferromagnetic transformer core with windings in an arrangement which firstly lends itself to the construction of a compact two phase resonant power converter, and secondly affords a large multiplicity of different output phases using only a single insulated secondary winding for each pair of output terminals.

According to this invention I provide an electrical converter which generates a polyphase alternating current output between pairs of output terminals, having a ferromagnetic ring core with two primary windings each comprising a pair of identically proportioned and diametrically opposed primary sections connected in series to cancel their nett magnetic effect around the circumference of said core, the said primary windings mounted with respect to two orthogonal planes so as to possess minimum mutual inductance one to another, said primary windings supplied with alternating currents in quadrature; said output terminals linked to electrically isolated secondary windings mounted on said core in predeterminable angular positions.

Preferably each of said pairs of primary coils is provided with a capacitor to form a resonant circuit, and said resonant circuits may be independently tuned to a desired operating frequency.

This arrangement is possible because magnetic flux will be present in the said ferromagnetic ring core mainly beneath the winding turns which carry current at the time, returning in the form of a stray field which leaves said ring core and flows parallel to the axis of the coil. Thus there will be stored energy associated with each primary coil in the manner of a solenoid, even though neither primary winding creates nett magnetic force around the core periphery. Such an arrangement contrasts with a conventional toroidal transformer.

It is then necessary to supply power to the two primary windings so that each maintains as closely as possible a sinusoidal voltage across itself, these two voltages being in quadrature. Given that said primary windings both resonate at a required working frequency, this may be achieved by using semiconductor or vacuum tube switches which connect each of said primary windings across a direct current power supply for a small proportion of the required cycle time, said primary windings being connected alternately and also the polarity of connection being reversed on each occasion. Between such periods of connection a sinusoidal pattern of magnetisation is maintained by current which flows through the capacitor associated with each primary winding.

The superposition of the two patterns of magnetic flux generated respectively by said two primary windings will constitute a non-uniform magnetisation of the said ferromagnetic ring core which is equivalent to the magnetisation which would be produced were a single pair of primary windings to be energised with direct current, and their mounting plane physically rotated about the axis of said ferromagnetic ring core at the rate of one revolution per cycle of alternating current generated. Such physical rotation would of course be impracticable at the frequency required for applications such as surgical diathermy, and so it is useful that the same result can be achieved by the present invention.

Given the set of primary windings already described, a secondary conductor may be threaded through the said ferromagnetic core and, if it is formed into a complete turn wrapped around any particular location on the circumference of said core, the said secondary conductor will be loosely coupled to both of said primary windings. It will generate an induced voltage which varies in phase according to its angular position, around the circumference of said ferromagnetic core with respect to said primary windings.

By providing secondary coils, each of a required number of turns and positioned suitably around the circumference of a ring-shaped ferromagnetic core and each wired between a pair of output terminals, it becomes possible to accommodate almost any number of output terminals and phase differences.

This arrangement is illustrated by Fig. 1 wherein a ferromagnetic ring core 1 is provided with four equally spaced windings numbered 2 to 5, of which windings 2 and 4 are connected directly in series opposition so as to constitute one primary winding producing no nett magneto-motive force round the circumference of the ring core 1. A capacitor 6 is connected across windings 2 and 4, in series, the aggregate inductance of which resonates with capacitor 6 at the desired operating frequency. Windings 3 and 5 are similarly connected so as to resonate with capacitor 7.
Electronic switches 8 to 15 connect the terminals of capacitors 6 and 7 to the opposing poles 16 and 17 of a direct current supply 18, the control inputs of said electronic switches being linked in pairs to control inputs 19 to 22 inclusive so that no one control input can cause a short circuit of supply 18. Driving circuits (not

shown) cause the control inputs 19 to 22 to be energised in the set sequence 19,20,21,22 with intervening "off" periods, which repeats so that the time for a whole cycle corresponds with the nominally equal resonant frequencies of the windings 2 and 4 with capacitor 6, and of windings 3 and 5 with capacitor 7.

It is further possible, instead of the said pairs of output terminals being independent, to connect said secondary windings together in a star or delta arrangement in order to constitute a single polyphase power source.

Insulated secondary windings 23 and 24, placed in desired angular positions on the ferromagnetic ring core 1, generate voltages at the operating frequency which differ in phase. In practice a desirable arrangement comprises more than two windings, which are symmetrically placed on the ring core 1 and linked into a star or delta configuration.

In an improved arrangement of windings, each primary winding is replaced by a pair of closely coupled bifilar windings to provide a balanced arrangement with a centre tap. Thereby the two said centre taps can remain permanently connected to one pole of a DC power supply, the four free ends of the said (composite) primary windings being connected in rotation to the opposite supply pole. Here four electronic switches will suffice to achieve the required pattern of energisation with time.

Fig. 2 depicts this improved arrangement of windings, and semiconductor switches. A ferromagnetic ring core 25 is provided with four bifilar windings 26 to 29 such that the two primary windings created by series connection of diametrically opposed winding sections, as in Fig. 1, may be centre tapped while the two halves of each primary winding so created remain closely coupled. This would not be the case if the individual windings of fig. 1 were to be separated by a centre tap.

Capacitors 30 and 31 are connected to resonate their corresponding primary windings, created by series connection as shown. The centre tap of each primary winding is connected to one pole 32 of a direct current supply 33, the opposing pole 34 of which is connected to semiconductor switches 35 to 38. whose control inputs 39 to 42 fulfil the same function as control inputs 19 to 22 in fig.1.

This invention further provides for the said control inputs to be driven by an electronic counter to provide the required pattern of power levels and magnetisation, noting that without a bifilar winding arrangement, it would be necessary for eight electronic switches to be connected in pairs to said electronic counter.

In a preferred arrangement using bifilar primary windings, a master oscillator operates at eight times the required operating frequency and drives a binary ring counter. Four semiconductor switches are actuated respectively by outputs 1,3,5, and 7 of the said counter, and link the four ends of said primary windings intermittently to one pole of a DC supply. The two centre taps of said primary windings are connected together to the opposite pole of said supply. The design of a commercially available electronic counter such as the industry standard type 4022 is such that at no time can two different outputs become energised simultaneously.

Fig. 2 shows how switches 35 to 38 are controlled by the outputs of 8-way binary ring counter 43. Said ring counter has a reset input 44 which forces a count of zero, whereby a voltage output exists at the "zero" output 47 (alone).

Hence, on applying a "reset" voltage to the counter its "zero" output alone is energised, and no power is drawn from the supply. With the counter running, the two resonant circuits are energised with a quadrature phase difference so that outputs of any required magnitude and phase are obtainable from secondary windings positioned as already described.

When said reset input voltage is removed, then an alternating voltage applied by generator 45 to count input 46 causes sequential voltage outputs to occur at each of the counter outputs 47 to 54 each lasting for one eighth the period of a complete cycle. The counter outputs 48, 50, 52 and 54 when they occur each switch on one of the switches 35 to 38 for a period corresponding to 45 degrees of a 360 degree cycle.

With reference to radio frequency amplifier technology known in the prior art, it will be recognised that the arrangement described above constitutes a pair of class C amplifiers whose conduction angle is fixed at 45 degrees. An improved arrangement provides that at least four of the said semiconductor switches, for example a MOSFET transistor, are controlled via an AND gate, the second input of which is controlled by a common pulse of variable length synchronised to the said master oscillator. This arrangement allows the proportion of the cycle, during which each of the said semiconductor switches conducts, to be variable and thus not only independently controllable, but also adaptable to offset the effects of variable load upon the system.

It will be seen that reset input 44 of ring counter 43 functions as a power on-off switch. Thus in a further improvement to this invention, a low frequency square wave is continually applied to the reset input of the said binary counter. This causes the power generation to be periodically interrupted so that measurements can be interposed which might be affected by the presence of radio frequency power, such as temperature checks during the progress of surgical diathermy.

In a preferred arrangement, the said low frequency square wave is applied via a monostable trigger circuit, which after delivering an energy pulse of known length requires to be returned to a starting condition by the output of a temperature sensor, said output being absent if said temperature exceeds a predetermined limit.

Fig. 2 illustrates how the output 55 of a conditionally monostable circuit built using 2-input NOR gates 55 and 56 may be connected to reset input 44 so that in the stable condition with input 58 at logic high, no power output results. The effect of maintaining input 58 at logic low is for repetitive pulses of power generation to take place (much greater than the cycle time of the ring counter 43 and typically in the order of one second as determined by resistor 60 and capacitor 59, with intervening periods of interruption. Input 58 is shown to be at a voltage controlled by temperature sensor 61 to give a form of thermostatic control. Safety conditions, such as the presence of electrical power at an undesired location, may also be arranged to cause inhibition by taking input 58 to logic high via diode 62.

CLAIMS

1. An electrical power converter which generates polyphase alternating current output between pairs of output terminals, having a ferromagnetic ring core with two primary windings each comprising a pair of identically proportioned and diametrically opposed primary sections connected in series to cancel their nett magnetic effect around the circumference of said core, the said primary windings mounted with respect to two orthogonal planes so as to possess minimum mutual inductance one to another, said primary windings supplied with alternating currents in quadrature; and electrically isolated secondary windings mounted on said core in predeterminable angular positions feeding said output terminals.

2. Apparatus according to claim 1 wherein said primary windings are provided with parallel capacitors forming two resonant circuits both tuned to a desired operating frequency, and switching means operating at four times said operating frequency or a multiple thereof to connect the extremities of said primary windings sequentially to an electrical power source so that substantially equal sinusoidal currents will flow through said primary windings in quadrature relationship, and substantially sinusoidal voltages will be induced in primary and secondary windings.

3. Apparatus according to a preceding claim having a plurality of secondary windings, connected in series with a consistent rotation of winding relative to the said core, with electrical loads connected between the junctions of said secondary windings, to form a polyphase power source of the delta configuration.

4. Apparatus according to a preceding claim having a plurality of secondary windings, with one end of each of said secondary windings connected to a common point, there being a consistent rotation of winding passing from said common point through each of said secondary windings, electrical loads being connected between the free ends of said secondary windings to form a polyphase power source of the star configuration.

5. Apparatus according to a preceding claim wherein each of said primary windings is wound with bifilar conductors, whereby each primary winding comprises two series combinations of diametrically opposed primary coils symmetrical about a tapping point, the winding sense being such that the inductances of adjacent bifilar conductors, connected in series, are additive.

6. Apparatus according to claim 5 wherein the said tapping points of the said primary windings are connected to one pole of a direct current supply, and the said switching means connects the extremities of said primary windings sequentially via electronic switches to the opposite pole of said direct current supply.

7. Apparatus according to a preceding claim wherein the electronic switching means is actuated by successive count outputs of an electronic counter, reset in synchronism with each magnetisation cycle of said ferromagnetic ring core.

8. Apparatus according to claim 7 wherein alternate count outputs of said electronic counter including the reset condition turn off said electronic switching means in order to reduce the duty cycle.

9. Apparatus according to claim 8 wherein the reset condition of the said electronic counter is cyclically imposed, and its removal is conditional upon the value of a physical parameter.

The Patent Office

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Application No: GB 9605617.1
Claims searched: 1 - 9

Examiner: John Watt
Date of search: 11 June 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1T (T1C, T1F, T6);
H2F (FDACS, FDACT, FDACX, FDAXS, FDAXT, FDAXX, FSTC)

Int Cl (Ed.6): H01F 21/06, 27/34, 29/12, 30/12, 30/14, 30/16, 38/38;
H02M 7/42, 7/44, 7/48, 7/53, 7/538

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 0432656	(ENGLISH ELECTRIC) see figure 3 and lines 59 - 94 of page 1	1

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.